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HYDROMORPHOMETRIC ANALYSIS AND PRIORITIZATION OF SAVITRI BASIN OF MAHARASHTRA, INDIA USING GIS

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ABSTRACT

Hydomorphometric properties of the river catchment helps in estimation of hydrologic response (runoff and sediment) from catchment and their management on watershed basis. Remote Sensing (RS) and Geographic Information System (GIS) are most appropriate, cost effective and quick technique for estimation of hydromorphometric properties over traditional methods. In Present study, linear, aerial and relief hydromorphometric properties were estimated using ASTERGEO DEM data in GIS environment (using ARC GIS 10.1 software) for prioritization of the Savitri basin in Konkan region of Maharashtra, India. The Savitri basin has total of 994 Sq Km and four sub catchments viz Ganhdari, Savitri, Kal and Bhaovira with runoff contributing area of each 137, 354, 332 and 47 Sq Km respectively. The time series analysis of rainfall and stream discharge from 1992 to 2011 shows increasing trends. The time of concentration of runoff of the Savitri basin was 6.7 hr for stream length of 57 Km. The drainage pattern was dendrites with VIIth highest drainage order. The drainage density is high and texture is observed as course in nature. The relief of the basin is high to moderate. The basin was found to be highly runoff producing and with moderate recharge capacity. The hypsometric analysis of basin indicates basin is mature in erosion process.

***KEYWORDS:** Savitri Basin, Hydromorphometry, Drainage, Relief, Aerial Hypsometric*

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Original Article

INTRODUCTION

Land and water resources are limited and their wide utilization is imperative, especially for countries like India, where the population pressure is increasingly continuously at alarming rate. Drainage basins, catchments and watershed are the fundamental units for administrative purposes to conserve natural resources (Mishra, 2010). The drainage basins are the response of slope, bedrock lithology, associate geology, and climate of that region which determines the characteristic of basins. Hence, quantitative analysis and their interrelationship are important to support decisions for various themes. Such as water resources development and their management, hydrologic responses and soil conservation practices adoption on watershed basis (Ogunkoya *et al*., 1984), etc. The hydromorphometric descriptors represent relatively simple approaches to describe basin attributes and find out their impact on the development of erosion process in the areas and to compare basin characteristics (Biswas *et al*., 1999) and enable to enhanced understanding of the geomorphic history of a drainage basin (Strahler, 1964). The method of quantitative analysis of drainage basins was developed by Horton (1945), and modified by Strahler (1964, 1969) but recently GIS and Satellite Remote Sensing technology provides a complete tool to analyze, to update and to correlate the measurements with periodic changes. Therefore, the results are more realistic

and less time consuming. Remote Sensing and GIS has effective tools to overcome most of the problems of land and water resources planning and management on the account of usage of conventional methods of data process (Umrikar *et al,* 2013). Geographical Information System (GIS) techniques provide a favorable environment and a powerful tool for the analysis and depiction of spatial information (Das and Mukherjee, 2005). The analysis of precipitation trends is important for monitoring the hydrologic response of watersheds to climate change. Similarly, the analysis of runoff trends is important for understanding human influence on hydrology (Mc Cabe and Wolock, 1997).

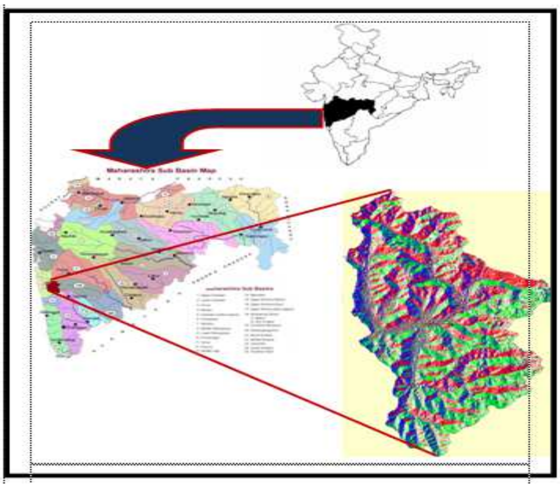

Figure 1: Location of Savitri Basin

This study was conducted to analyze hydromorphometric parameters of Savitri Basinin in Konkan Region of Maharashtra comes under Western Ghat of South Tapi tributaries. The hydrological (Runoff and sediment) response behavior of the watershed obtained helps in prioritization and characterization for suitable soil and water conservation management alternatives in GIS environment.

MATERIALS AND METHODS

Study Area

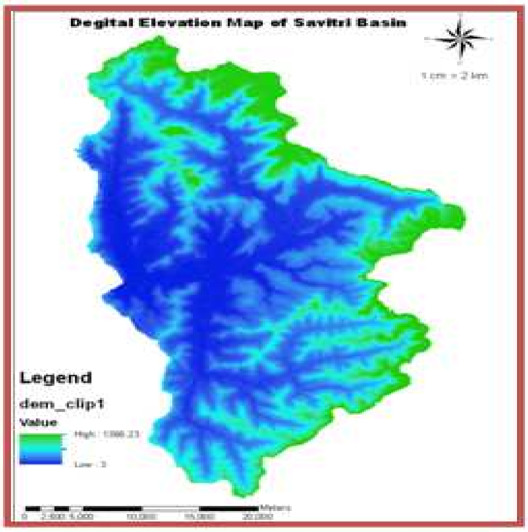

Figure 2: Digital Elevation Model of Savitri River Basin

The Savitri river basin comes under the Western part of Sahayandri Ghat part of Konkan region and located in Maharshtra State of India. It started from Mahabaleswar in Sahayandri ranges and fed to Arabian Sea with total contributing area at Mahad outlet is 994 sq km (Figure 1). The latitude and longitude of the study area is $18^{0}20'$N to $17^{0}51'$N and $73^{0}22'$ E to $73^{0}41'$E respectively and elevation ranges from 6.50 m to 1366.23 m above mean sea level**.** The main stream under the study is Savitri basin, has average length of 57.57 Km. The Savitri basin comprises of four rivers namely Gandhari, Kal, Savitri and Bhaovira having catchment area of 137, 332, 354 and 47 Sq. Km respectively. Each has hydrological and meteorological gauging stations located at Koturde, Birwadi, Kangule and Bhave at their outlets point. The region falls within sub-tropical climate with alternate dry and wet periods with three well defined seasons i.e. summer, monsoon and winter with average annual rainfall is 3560 mm in the form of intense storms and its distribution is highly erratic as more than 90 per cent is occurred during the monsoon months (June to October). Daily mean temperature ranges from a maximum of 35^{o}C (May) to minimum of 21^{o}C (January). The daily mean relative humidity varies from a minimum of 55.15 per cent (April) to a maximum of 99 per cent (July). The Mean daily evaporation, Wind speed and Sunshine hours were 4.66 mm, 2.48 m/s and 11.12 hours, respectively. The soil is sandy loam (73.6 per cent) to clay loam (26.4 per cent) in texture. Most of the watershed comes under degraded land with less soils depth (25-50 cm).

METHODOLOGY

The remotely sensed data coupled with topographical data analysis procedures have made satellite sensor data based hydromorphometric analysis a highly effective tool to understand and manage the natural resources. An attempt has been made to utilize the interpretative techniques of GIS to find out the relationships between the morphometric parameters of Savitri river basin. Hydromorphometric properties of the Savitri basin were estimated from ASTERGEO 10 DEM (Figure 2) with 30 m resolution in ARC GIS 10.1 software using hydrology tool. The parameter related to linear, aerial and reliefs were estimated with different formulae given in Table 1. The various aspects were studied for their inter-relationship which helps to depict the nature of the sub-catchments.

Trend Analysis of Rainfall (P) and Runoff (Q)

Trend analysis of rainfall and stream flow of Savitri basin was analyzed. Runoff (Q) is due to the change in precipitation (P) or due to other factors (land cover change). The runoff coefficient (Q/P) has derived with different parameter such as mean, Rate of change (ROC), Seasonal Mann Kandla Test (SMK) (Mann, 1945)). Its significance to flow pattern of the basin with different sub catchments, SMK statistic, variance, and 5% significance level (p-value $\leq$ 0.05) were also estimated. The ariance was corrected for ties and serial dependency.

Table 1: Formula Adopted for Computation of Hydromorphometric Properties

Sr No.	Properties	Formulae*
A)	Linear Morphometry	
i)	Stream number in each order (N_o)	Hirachecal order
ii)	Total strteam number inn basin (N)	$N = \frac{R_b{}^s - 1}{R_b - 1}$
iii)	Average stream length (Lo)	$\bar{L}_0 = \bar{L}_1 R_L{}^{o-1}$
iv)	Total stream length (Lo)	$L_o = \bar{L}_1 R_b{}^{s-1}\left(\frac{u^s - 1}{u - 1}\right)$ where $u = R_L/R_B$
v)	Bifurcation ratio (Ro)	$R_b = N_o/N_{o+1}$
vi)	Length ratio (R_L)	$R_L = \bar{L}_o/\bar{L}_{o+1}$

Table 1: Contd.,		
vii)	Length of overland flow (λo)	$\ell_o = \frac{1}{2D}$
B)	Areal Morphometry	
i)	Stream area in each order(A_0)	$\bar{A}_o = \bar{A}_1 R_a{}^{o-1}$
ii)	Length area (L)	$L = 1.4A^{0.6}$
iii)	Basin shape(R_f)	$R_F = \frac{A_o}{L_b{}^2}$
iv)	Drainage density(D_d)	$D = \frac{\Sigma L}{A}$
v)	Stream frequency (F_s)	$F_s = \frac{N}{A}$
vi)	Constant of channel maintenance (C)	$C = \frac{1}{D}$
C)	Relief Morphometry	
i)	Relief ratio (R_h)	$R_h = H/L_o$
ii)	Relative relief (R_{hp})	$R_{hp} = H/p$
iii)	Relative basin height (y)	$y = h/H$
iv)	Relative basin area (x)	$x = a/A$
v)	Ruggedness number (R)	$R = DH$
vi)	Time of Concentration (T_c)	$T_c = 0.0195L^{0.77} S^{-0.385}$

*Adopted from Strahler (1964)

RESULTS AND DISCUSSIONS

Morphometric Properties

Linear Aspects

The drainage order of Gandhari, Kal, and Bhaovira were Vth Whereas Savitri River has VIth order (Table 2). The overall Savitri basin has highest drainage order of VIIth. The total number stream 1101, 1990, 1887 and 262 were observed for Gandhari, Savitri, Kal and Bhaovira rivers respectively whereas Savitri basin has 5960. There are highest numbers of steams observed in Ist order and it is followed by IInd order, IIIrd order and so on. Total stream length of Gandhari, Savitri, Kal and Bhaovira rivers were 295.22, 650.08, 649.70 and 92.82 Km respectively and of Savitri Basin was 1759.8 Km. The stream length is decreasing with increases the stream order. The mean stream length is directly related to the drainage density and basin shape. The lowest length ratio is observed for Gndhari as compared to other rivers and It is highest for Bhaovira river, because of rivers shape and drainage order. The highest bifurcation ratio has observed for low order streams and it decreases consequently with increasing stream drainage increases for all sub catchments. The bifurcation ratio is the resultant of the shape and drainage characteristic of the rivers catchments. Horton (1945) expressed it as equal to half of the reciprocal of Drainage Density ($D_{d)}$. The lowest overland flow has observed for Gandhari river and highest for Savitri river. Lowest value represented the time of concentration for accumulation of flow is less whereas highest value repressed more. It is factor dependent of drainage density mean all factor i.e relief, slope and length of stream play important role in flow accumulation.

Table 2: Linear Geomorphologic Aspect of Savitri Basin and its Tributaries

SI. No	River/ Basin	Order, (U)	No. of Streams, (N_u)	Total Steam Length, km	Mean Stream Length, km	Length Ratio, (R_L)	Bifurcation Ratio, (R_b)
1	Gandhari	Vth	1101	295.22	0.27	1.86	2.12
2	Savitri	VIth	1990	650.98	0.33	2.28	2.28

Table 2: Contd.,							
3	Kal	V^{th}	1887	649.76	0.34	1.91	1.89
4	Bhao Vira	V^{th}	262	92.82	0.35	2.64	3.54
5	Savitri Basin	VII^{th}	5960	1759.8	0.30	2.19	2.27

Aerial Aspects

The total stream area of Gandhari, Savitri, Kal and Bhaovira rivers were 137.0, 354.0, 332.0, and 47.0 Sq Km respectively and of Savitri Basin is 994.0 Sq Km (Table 3). The length area of Gandhari, Savitri, Kal, Bhaovira rivers and Saviti Basin were 26.81, 47.37, 45.58, 14.11 and 88.02 Sq Km respectively. The perimeter were 59.0, 97.0, 112.0 33.0 and 176.0 Km for Gandhari, Savitri, Kal, Bhaovira rivers and Saviti Basin respectively. The shape of the basin mainly governs the rate at which the water is supplied to the main channel. The main indices used to analyze basin shape and relief is the elongation and relief ratios. Basin shape **(**Form factor, R_f) is the numerical index (Horton, 1932) commonly used to represent different basin shapes. The value of form factor for Savitri Basin is 0.03 and for Gandhari, Savitri and Bhaovira is 0.04 whereas for Kal river is 0.03 (Table 3). This high form factor value indicates that the watershed has high peak flows for shorter duration (Chakraborty *et a*l 2002). Low form factor ratio will be for basins of flatter peak flow for longer duration (Biswas,1999) with less side flow for shorter duration and main flow for longer duration (Reddy, 2002), and vice versa for high ratio. The Drainage density (D_d) of Gandari rivers has highest compared to Savitri and Kal river and overall Savitri Basin has 1.77. Savitri Basin has drainage texture over all its tributaries. The Basin has circular to elongate, which is inversely related to character of movement of runoff at outlet and infiltration. The Channel maintenance constant is approaching to 0.5 indicates less soil depth and more erosion from the surface with high steep slops.

Relief Aspects

The highest relief ratio has found for Bhaovira river whereas it was lowest for Kal river. The Savitri Basin has relief ratio as 0.03 (Table 4). The relative relief of Savitri basin was observed as 0.01. It is much low as compared as slope parameter. The average slope of basin observed was

Table 3: Aerial Geomorphologic Aspect of Savitri Basin

SI No	Parameters	Gandhar	Savitri	Kal	Bhao vira	Savitri Basin
1	Stream area (A), Sq Km	137.00	354.00	332.00	47.00	994
2	Length area (La), Sq Km	26.80	47.37	45.58	14.11	88.02
3	Perimeter (P), Km	59.00	97.00	112.00	33.00	176.00
4	Basin length (L), Km	21.3	24.55	34.34	10.79	52.85
5	Width of Basin (W), Km	8.61	24.29	13.02	7.02	26.12
6	Length of Main stream (Lb), Km	22.63	35.95	31.68	11.99	57.29
7	Shape Factor (Rf)	0.04	0.04	0.03	0.04	0.03
8	Drainage density (Dd)	2.15	1.84	1.96	1.97	1.77
9	Drainage frequency (Fs)	8.04	5.62	5.68	5.57	6.00
10	Drainage texture (Rt)	18.66	20.52	16.85	7.94	33.86
11	Elongation ratio (Re)	0.31	0.43	0.30	0.36	0.34
12	Circularity ratio (Rc)	0.49	0.47	0.33	0.54	0.40
13	Length of overland flow (λ_0)	0.23	0.27	0.26	0.25	0.28
14	Constant of Channel Maintenance (C)	0.46	0.54	0.51	0.51	0.56

3.99 per cent. The channel slope of Savitri basin was 24 per cent whereas for Bhaovira. It may due to low channel length and highest channel elevation difference. Ruggedness number (Strahler (1969) which slope steepness with its length and it was 2.41 for basin. Time of concentration (Tc) of Savitri Basin was 6.47 hr for travel length of 57.48 Km (Table 4).

Table 4: Relief Geomorphologic Aspect of Savitri Basin

SI No	Parameters	Gandhari	Savitri	Kal	Bhao vira	Savitri Basin
1	Height of height point on the Basin, max H, m	849.10	1366.23	1141.25	1028.11	1366.23
2	Lowest point of the river basin, min H, m	6.38	8.07	23.85	23.85	5.25
3	Total Basin Relif (Bh)	842.72	1358.16	1117.40	1004.26	1360.98
4	Relief ratio (Rh)	0.04	0.06	0.03	0.09	0.03
5	Relative relief	0.01	0.01	0.01	0.03	0.01
6	Ruggedness number (Hd)	1.82	2.50	2.19	1.98	2.41
7	Channel slope, Percent	3.73	3.77	3.53	8.37	2.27
8	Average Basin slope, Per cent	4.47	4.00	4.32	7.34	3.99
9	Time of concentration Tc (hr)	2.37	3.36	3.18	1.22	6.47

Hydromorphometric Properties

Density & Frequency/Bifurcation Ratio (D/Rb & F/Rb)

The relationship between bifurcation ratio and drainage density/or helps to assessing flood-prone areas as well as to determine groundwater potential zones. This relation is usually established graphically between *Dd/Rb* and *F/Rb*, thus compared to dedicated illustrations obtained by Al-Shamy (1992) (Table 5). The obtained illustrations for *Dd/Rb* and *F/Rb* were plotted. Each illustration contains two curves, thus divided the area into three zones A, B and C (Figure 3). According to Al-Shamy (1992), these zones are described as follows:

- **Zone A:** Low flood probability and high recharge property
- **Zone B:** High flood probability and low recharge property
- **Zone C:** Moderate to high flood probability and moderate recharge property.

The resulting graphics show that all River-catchments except Bhaovira are located in zone C, and thus characterized by moderate to high flood probability and moderate water recharge property (Figure 3).

Table 5: Basic Principle Morphometric Variable of Savitri Basin

River /Catchment	Stream Order	Area, Sq km	Stream Length, km	Total Stream Numbers, Nu	D_d	F_s	R_b	D_d/R_b	F/R_b	Basin* Assessment
Gandhari	V	137.00	295.22	1101	2.15	8.04	2.12	C	C	C
Savitri	VI	332.00	650.98	1990	1.84	5.62	2.28	C	C	C
Kal	V	354.00	649.76	1887	1.96	5.68	1.89	C	C	C
Bhao vira	V	47.00	92.82	262	1.97	5.57	3.54	C^-	B	B
Savitri Basin	VII	994	1759.8	5960	1.77	6.00	2.27	C	C	C

***According to Al Shamy (1992.**

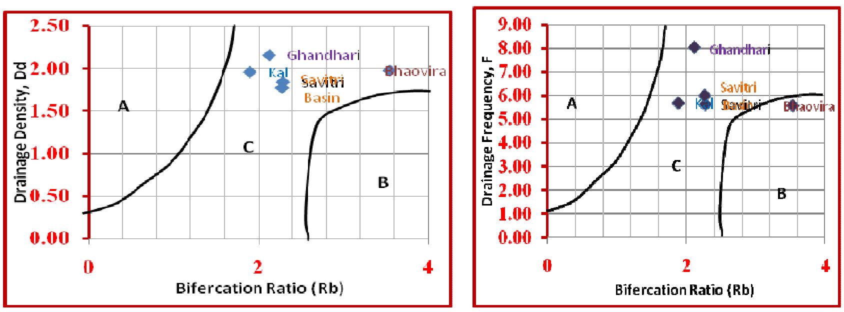

Figure 3: Assessment of the River Catchments to Floods and Recharge Property

Hypsometric Analysis (Hs) and Integral (Hi)

The form of hypsometric curve and the value of the integral are important elements in topographic form (Strahler, 1952). It show marked variations in regions differing in stage of development and geologic structure, because in the stage of young hypsometric integral is large but it decreases as the landscape is denuded towards a stage of maturity and old age (Strahler, 1952). The following parameters were estimated from contour map of the Savitri Basin as per suggestions of Pareta and Pareta, 2012.

- a / A, where 'a' is the area enclosed by a pair of contours, and 'A ' is the total basin area which is represented on the abscissa; and
- h / H, where 'h' is the highest elevation between each pair of contours above the base, and 'H' is the total basin height.

The hypsometric curves obtained are graphical plots and shown in Figure 4. It is decreasing with decreasing area ratio. The hypsometric and erosion integrals calculated from the percentage hypsometric curve, give accurate knowledge of the stage of the cycle of discussion. The hypsometric integral (King, 1966) of Savitri Basin was 26.42 % and the erosion integral of the watershed is 73.58 %, which indicates the Savitri Basin is at mature old stage.

Table 6: Trends Analysis of Rainfall and Stream flow using Mann Kendall Test

River Catchments	Hydrologic Station	Rainfall, P					Runoff, Q			
		Aarea, Sq Km	Mean, mm	Rate of Change	MK Coefficient, U(t)	Trend Significance (Level of at 95 %)	Mean, Mm	Rate of Change	MK Coefficient, U(t)	Trends (at 95 % Level of Significance)
Gandhari	Kokre	137	3927.26	1.5	-0.011	decreasing	1409.85	1.6	0.216	increasing
Kal	Birwadi	332	3900.910	1.6	0.239	Increasing	1708.94	1.5	0.152	Increasing
Savitri	Kangule	354	3421.68	2.8	-0.020	decreasing	1680.50	2.5	0.118	Increasing
Bhovira	Bhave	47	3598.31	2.5	0.145	Increasing	1712.59	-2.6	0.333	Decreasing
Savitri Basin	Mahad	994	3533.95	1.6	0.007	Increasing	1308.95	1.8	0.009	Increasing

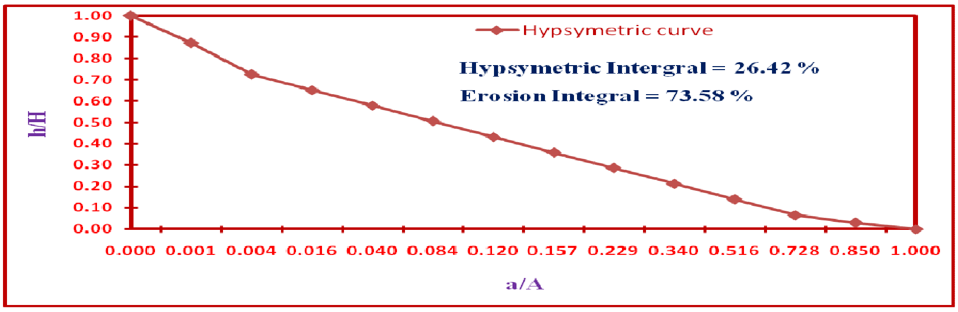

Figure 4: Hypsometric Curve of Savitri Basin

Trends Analysis of Rainfall (p) and Runoff (Q)

It is observed form above Table 6 that, the Savitri basin receiving rainfall with mean of 3534 mm with increasing Trends and same trends is observed for stream flow as well. MK test and ROC shows positive value indicating the stream flow increasing trends, it may be due to increases urbanization over last decade.

CONCLUSIONS

The hydromorphometric analyses were carried out through measurement of hypsymetric analysis, Density & Frequency/Bifurcation Ratio from linear, areal and relief aspects of the watershed. The morphometric of drainage network of the watershed shows dendrite and radial patterns with moderate drainage texture. The variation in stream length ratio might be due to change in slope and topography. The bifurcation ratio in the watershed indicates normal watershed category and the presence of high drainage density suggesting that it has moderate permeable sub-soil, and coarse drainage texture. The hypsometric erosion integral was 26.47 per cent and time of response of Savitri basin was 7.85 hrs. The Savitri Basin has been divided into four sub river catchment viz Gandhari, Kal, Savitri and Bhaovira. It is observed that Bhaovira has high flood porn and less recharge capacity compared to other rivers. The Savitri basin is found to be an old and mature basin in erosion process. It is also observed that, basin response to rainfall to runoff process was increasing trends; it may due to increasing urbanization in the basin and reducing vegetation.

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